U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

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Initiated by: AFS-200 **Change:**

Subject: Basics of Aviation Fatigue

1. **PURPOSE.** This advisory circular (AC):

- Summarizes the content of the FAA international symposium on fatigue, "Aviation Fatigue Management Symposium: Partnerships for Solutions", June 17-19, 2008;
- Describes fundamental concepts of human cognitive fatigue and how it relates to safe performance of duties by employees in the aviation industry;
- Provides information on conditions that contribute to cognitive fatigue; and
- Provides information on how individuals and aviation service providers can reduce fatigue and/or mitigate the effects of fatigue.

2. **APPLICABILITY.** This AC is not mandatory and does not constitute a regulation.

3. **DEFINITIONS.**

a. Circadian Challenge. Circadian challenge refers to the difficulty of operating in opposition to an individual's normal circadian rhythms or internal biological clock. This occurs when the internal biological clock and the sleep/wake cycle do not match the local time. For example, the sleep period is occurring at an adverse circadian phase when the body wants to be awake. Engaging in activities that are opposite of this natural biological system represents the circadian challenge (e.g., night work, shift work, jet lag).

b. Cognitive Performance. Cognitive performance refers to the ability to process thought and engage in conscious intellectual activity, e.g., reaction times, problem solving, vigilant attention, memory, cognitive throughput. Various studies have demonstrated the negative effects of sleep loss on cognitive performance.

c. Circadian Rhythm. A circadian rhythm is a daily alteration in a person's behavior and physiology controlled by an internal biological clock located in the brain. Examples of circadian rhythms include body temperature, melatonin levels, cognitive performance, alertness levels, and sleep patterns.

d. Circadian Synchrony. Circadian synchrony occurs when a person's internal biological clock matches the local external time cues (e.g., light/dark cycle, social interaction). In other words, sleep opportunities occur when the body wants to sleep and waking activities take place when the body is promoting wakefulness and alertness.

e. Endogenous Circadian System. The endogenous circadian system refers to the biological clock in the brain that programs humans to be awake during the day and asleep at night. It also regulates alertness, performance, and sleepiness levels through the 24-hour day. This internal system persists independent of periodic changes in the external environment based on the time of day and can be modified or reset by environmental inputs such as light.

f. Fatigue. Fatigue refers to a physiological state in which there is a decreased capacity to perform cognitive tasks and an increased variability in performance as a function of time on task. Fatigue is also associated with tiredness, weakness, lack of energy, lethargy, depression, lack of motivation, and sleepiness.

g. Fatigue Risk Management System (FRMS). FRMS is a scientifically based, data-driven process and systematic method used to continuously monitor and manage fatigue risks associated with fatigue-related error. FRMS can be, but is not necessarily required, a fundamental part of an organization's Safety Management System (SMS).

h. Homeostatic Sleep Drive. The homeostatic sleep drive is a fundamental neurobiological process involved in the timing and placement of sleep through a 24-hour day. Sleep is a vital physiological need and is critical to human existence. Good sleep is as important to health and well-being as proper nutrition and good exercise. The average adult sleep need is about 8 hours each day.

i. Safety Management System (SMS). An SMS is a coordinated, comprehensive set of processes designed to manage resources for optimal safety achievement. An SMS is a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies, and procedures representing a management approach to controlling risk.

j. Sleep Inertia. Sleep inertia (also termed *sleep drunkenness*) refers to a period of impaired performance and reduced vigilance following awakening from the regular sleep episode or nap. This impairment may be severe, last from minutes to hours, and be accompanied by micro-sleep episodes.

k. Time Givers. This concept comes from the German word, "zeitgeber," which represents any external cue that entrains or aligns humans' internal time-keeping system with external stimuli. The strongest zeitgeber is light. Other time givers include temperature, social interactions, pharmacological manipulation, and eating/drinking patterns.

l. Window of Circadian Low (WOCL). Individuals living on a regular 24-hour routine with sleep at night have two periods of maximum sleepiness, also known as "WOCLs." One occurs at night, roughly from 3 a.m. to 5 a.m., a time when physiological sleepiness is greatest and performance capabilities are lowest. The other is in the afternoon, roughly from 3 p.m. to 5 p.m.

4. RELATED READING MATERIAL.

- Proceedings of the Aviation Fatigue Management Symposium: Partnerships for Solutions, June 17-19, 2008.

- Caldwell, J. A.; Caldwell, J. L. Fatigue in Aviation: A Guide to Staying Awake at the Stick (Studies in Aviation Psychology and Human Factors). Ashgate Publishing Limited; 2003.

- Dinges, D. F.; Graeber, R. C.; Rosekind, M. R.; Samel, A.; Wegmann, H. M. Principles and guidelines for duty and rest scheduling in commercial aviation. Moffett Field, CA: NASA Ames Research Center; 1996. Report No.: 110404.

- Dinges, D.; Mallis, M.; Bankls, S. Aircrew Fatigue & Circadian Rhythmicity (Chapter 13). In Elsevier, E. Salas, T. Allard, & D. Maurino, (Eds), Human Factors in Aviation (2nd edition), Academic Press; 2009.

- Rosekind, M. R.; Gander, P. H.; Connell, L. J.; Co, E. L. Crew Factors in Flight Operations X: Alertness Management in Flight Operations Education Module. (NASA Technical Memorandum 2001-211385 DOT/FAA/AR-01-01). Moffett Field, CA: NASA Ames Research Center.

5. BACKGROUND. The traditional definition of fatigue is a physiological state in which there is a decreased capacity to perform cognitive tasks and an increased variability in performance. While fatigue is often attributed to periods of extended wakefulness in which ample recovery sleep is not obtained, research has shown that performance and alertness levels are largely influenced by the complex interaction between sleep and the 24-hour biological clock (circadian rhythm). In addition, time on task can further increase fatigue. Although research has established empirically-based knowledge of sleep and circadian principles, current regulations, policies, and practices do not incorporate this scientific research [31]. Thus, the challenge of fatigue among aviation employees has steadily increased along with fatigue-related concerns over air safety, due to increasingly complex operations that continue around-the-clock. Accident statistics, reports from pilots themselves, and operational flight studies all show that fatigue is a clear concern within aviation operations.

a. Risk Factors. Fatigue associated with aviation operations is a risk factor for occupational safety, performance effectiveness, and personal wellbeing. The multiple flight legs, long duty hours, limited time off, early report times, less-than-optimal sleeping conditions, rotating and non-standard work shifts, and jet lag pose significant challenges for the basic biological capabilities of pilots, crewmembers and shift workers. Humans simply are not designed to operate to operate effectively under the pressured 24/7 schedules that often define aviation operations, whether the operations are short-haul commercial flights, long-range transoceanic operations, or around-the-clock and shift work operations.

b. Personnel Reports. Short-haul (domestic) pilots commonly identify sleep deprivation and high workload as the main factors contributing to their fatigue. Long haul crewmembers generally attribute sleep deprivation and circadian disruption caused by multiple time-zone crossings as the main causes of fatigue [11]. However, fatigue resulting from multiple flight legs, early wake times, consecutive duty days, insufficient recovery sleep periods, time demands, and jet lag are reported by both short-haul and long-haul flightcrew. Corporate/executive crews experience similar fatigue-related problems when compared with their commercial counterparts; however, scheduling issues (multi-segment flights, night flights, late arrivals, and early awakenings) are the most salient contributing factors to fatigue [75]. Pilots also report weather and turbulence as contributing factors. Shift workers in aviation operations face a different set of fatigue drivers that affect the same underlying physiology. Because shift patterns can vary widely, the cause of shift work fatigue can be one or more of a variety of factors. These factors are night work that deprives a person of normal nighttime sleep, insufficient time between shifts to get recovery sleep, rotating shifts that force adjustment of the body clock to constantly changing sleep/wake patterns, and early start times that can shorten nighttime sleep.

6. THE FATIGUED BRAIN.

a. 24-Hour Biological Rhythms. Most organisms show daily behavioral and physiological changes that are cyclical across the day. A biological clock located in the brain controls these 24-hour cycles in humans—circadian rhythms [64] (see Figure 1). Circadian rhythms result in two periods of sleepiness (nadirs) throughout the day; the maximum sleep propensity occurs during the early morning (the latter half of the habitual sleep episode), and the second period of increased sleep propensity occurs in the mid-afternoon [26, 86]. Time givers, environmental stimuli such as the light/dark cycle and social cues also influence circadian rhythms. These time givers help to synchronize (entrain) circadian rhythms to the 24-hour day. However, in the absence of external time cues, the circadian cycle is slightly longer with a free running period of 24 to 28 hours [21]. Core body temperature is a reliable marker of fluctuations in the 24-hour clock. People have increased feelings of sleepiness and reduced performance levels when core body temperature reaches its low point, or nadir [23]. This rhythm affects many dimensions of cognitive performance (see below) but the most obvious change is an increase in reaction time and tendency to have lapses in attention often associated with short sleep attacks (micro-sleeps).

b. Sleep. In addition to the circadian component, the daily pattern of sleep strongly modulates alertness and cognitive performance.

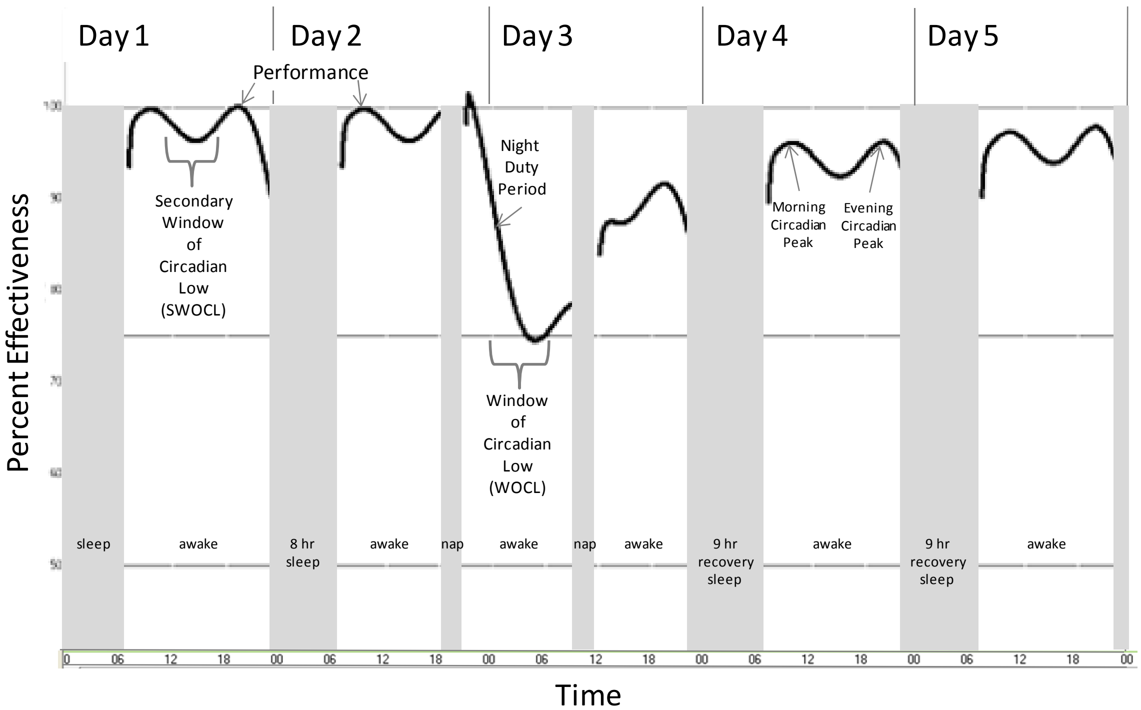
(1) The brain requires a regular pattern of sleep to be fully functional and regulates the drive to sleep in order to restore alertness and performance.

(2) The average person usually needs about 8 hours of sleep per day to remain fully alert and functional.

7. FOUR SLEEP-RELATED PROCESSES TO UNDERSTAND.

a. Sleep Regulation. The drive for sleep increases over time since the last sleep period and with any cumulative deficit in sleep relative to the average 8-hour day requirement. As a consequence, the sleep drive is at its lowest point in the morning, upon awakening, and as the day progresses, the drive to sleep increases and the ability to sustain attention and engage in cognitive activities decreases. Once sleep begins, this drive gradually decreases until awakening. The system is homeostatic in the sense that the more a person is deprived of good quality sleep (relative to the nominal 8-hour requirement), the stronger the drive for sleep. The two main fatigue processes—24 hour (circadian) rhythm and sleep regulation—combine to produce dynamic changes in sleep tendency and ability to maintain stable alert performance across a 24-hour period and across days (see Figure 1).

FIGURE 1. CIRCADIAN PATTERN OF PERFORMANCE



b. Elevated Sleep Drive. For the average person, the daily upswing in alertness produced by the circadian system tends to offset the decrease in alertness produced by depletion of the sleep regulatory process. The result is roughly constant reaction time and lapses during the first 16 hours of the day [85]. After about 16 hours of continuous wakefulness, most adults begin to notice reductions in the speed of performance and in alertness levels [87]. However, a prior history of insufficient sleep quantity and quality can magnify the changes in behavior and alertness. Consequently, three factors can result in elevated homeostatic sleep drive:

- Increasing time continuously awake,
- Inadequate sleep duration for one or more consecutive days,
- Physiologically disrupted (fragmented) sleep due to medical conditions (e.g., untreated sleep disorder such as obstructive sleep apnea) or environmental factors (e.g., attempting to sleep upright or in an uncomfortable environment).

c. Desynchronization. The timing of sleep and wakefulness of most humans, under natural conditions, is consistent with the circadian control of the sleep cycle and all other circadian-controlled rhythms. However, people working in a developed society override their internal biological clock and attempt to sleep at times that are not always consistent with the biological drive to sleep. For example, when individuals travel rapidly across time zones or work the night shift, the sleep/wake cycle is out of phase with the biological rhythms controlled by the circadian clock. This can adversely affect both alertness while awake and at work, and the ability to achieve restorative sleep [23]. This sort of disruption of circadian synchrony can result in difficulties, such as impaired cognitive function, sleepiness, altered hormonal function, and gastrointestinal complaints [72, 76].

d. Sleep Inertia. This sleep-related process causes a temporary degradation in performance immediately after awakening. The degradation or loss of alertness is dependent on depth of sleep at the time of awakening. The degradation dissipates, after awakening, on a time scale ranging from minutes to a few hours (see Figure 1). Sleep inertia causes a feeling of drowsiness or lethargy and can be measured as a noticeable change in reaction time and potential for lapses in attention. The duration and severity of sleep inertia is related to the depth of sleep at the time of awakening. It tends to be greater after short sleep periods of an hour or two, when the need for sleep is not fully satisfied, or after sleep when the person is carrying a large sleep debt from prior sleep restrictions [10, 23, 88].

8. EFFECTS OF FATIGUE ON HUMAN PERFORMANCE.

a. Cognitive Performance is a Safety Critical Process. Maintaining optimal alertness and neurobehavioral functioning in operational environments is critical for achieving high levels of safety, efficiency, and success. High levels of alertness and performance are necessary to operate complex technology and machinery as well as to make critical task decisions on a sustained basis. Individuals working erratic schedules experience conflicts between the biological circadian rhythm and environmental time cues and work demands. This physiological conflict can cause a sense of drowsiness (subjective fatigue), mood changes, performance degradation, and physiological upset [44]. Two adverse effects of the circadian conflict between the sleep/wake pattern and the biological rhythm worsen performance levels and sleepiness:

- Trying to sleep when a person's biology is highly energized, and
- Attempting to maintain alertness and high cognitive functioning at a time when a person's biological clock is programming the body to sleep.

(1) Figure 1 is a diagram of performance across days and illustrates the circadian patterns in performance (dark line). There are two peaks in performance—one in the late morning and one in the early evening. After about 7 p.m., the circadian rhythm in performance begins to decline and if the person stays awake throughout the night, as on Day 3, will experience a strong early morning low (nadir) in performance referred to as the WOCL—generally between 3 a.m. and 5 a.m. This is a period of generally low alertness and performance and elevated operational risk; it is also the optimal time to obtain restorative sleep. There is a secondary dip in alertness in the early afternoon, referred to as the secondary WOCL, which is a period of increase drowsiness and performance risk lasting for several hours. The secondary WOCL is a relatively good time to obtain a brief nap, if additional sleep is necessary. The exact synchronization of this rhythm with the clock varies somewhat from individual to individual, and the relative size of the morning and evening peaks in performance also varies between people [43, 52]. We refer to those who feel best in the morning as "larks" and those who feel most energized in the evening as "owls." The person diagrammed in Figure 1 is neutral with approximately symmetrical peaks in morning and evening performance.

(2) In Figure 1, note that on Day 3, after missing a single night of sleep and having a 3 hour nap in the morning, evening performance is about 10 percent below what it would be on a normal day, see Day 1. The effect of this single period of sleep deprivation has lasting effects; after 2 days of recovery with 9 hours of sleep, performance is not fully recovered. For this hypothetical person, it would take an additional day to recover full capability.

b. Objective Performance Changes. Laboratory and simulator studies have documented changes in all aspects of neurobehavioral functioning associated with fatigue and sleep loss. As little as 2 hours of sleep loss a day can result in impaired performance and alertness [19], and the decrements are especially apparent during late night and early morning hours [62]. Although the degree to which sleep loss affects individuals and how that sleep loss is expressed varies greatly among people [36, 48, 87], all fatigued and sleepy individuals begin to have decrements in attention and vigilance. Total sleep deprivation is not necessary to produce profound changes in performance. When sleep is restricted over successive days, serious cumulative performance deficits can occur in less than 1 week [3, 34, 87]. For example, 4 days of sleep restriction from 8 hours to 5 hours sleep per night can lead to performance changes as severe as that produced by 40 hours of total sleep deprivation. Lapses, brief periods in which an individual fails to respond to a stimulus, increase in frequency and duration as sleepiness levels increase [29, 32]. Other notable and observable performance decrements are [6, 18, 29, 32, 47, 65, 92]:

- Slowed reaction times;
- Cognitive slowing (logical reasoning, mental arithmetic, coding-decoding);
- Difficulties maintaining situational awareness; and
- Impaired short-term memory.

c. Error Rates. People working regular 24-hour sleep/wake schedules with sufficient time to sleep will experience little change in performance and subjective fatigue during waking hours from 1 to 2 hours after awakening to 1 to 2 hours before sleep onset [22, 51]. However, in many work environments, an increase in error rates and accident likelihood often occurs in the early afternoon, between 2 p.m. and 4 p.m. It is followed by a much larger increase in risk in the early morning hours between 2 a.m. and 4 a.m. that roughly coincides with the minimum of the circadian rhythm of core body temperature, as illustrated in Figure 1 [10, 38, 54, 90].

d. Subjective Fatigue. People are not the best evaluators of their own alertness state. People can lose awareness of their own fatigue levels. They are often sleepier than they report. Although individuals report feeling increasing levels of sleepiness and fatigue with the progression of sleep loss, research has shown that these subjective estimates are unreliable [27, 49, 74, 95]. Environmental conditions can affect subjective estimates. If an individual is in a highly engaged environment involving physical activity or interaction with other individuals, the person's underlying sleepiness may not be noticeable and that person may rate him or herself as being more alert than his or her physiological responses indicate. This creates challenges for detecting and managing alertness and cognitive capability in operational environments because individuals often do not notice the gradual changes in performance until it is too late to take corrective action [33, 58].

e. Mood. Fatigue can affect overall mood. Sleepy individuals often show deteriorations in mood and have reductions in amount and quality of communication and social interaction with other individuals. This can have serious consequences for crews and workgroups that rely on the exchange of information to provide mutual support and avoid errors. Workers often report workload as an important component of subjective fatigue. A flightcrew that performs many flight segments in a duty period will report more subjective fatigue than a crew that has a single flight segment taking the same amount of time [11]. It is not known if this kind of fatigue results in reduced neurobehavioral functioning but it can combine with actual sleep loss to amplify the sense of fatigue reported by crewmembers. Time on task can also increase fatigue and accident risk. Studies show that after 8 hours of uninterrupted work, chances of error and accidents increase. Providing short breaks from work can greatly attenuate this effect [39].

9. SOURCES OF FATIGUE IN AVIATION.

a. Flight Operations. Sleep loss is one of the primary contributors to fatigue in flightcrew and is directly related to a variety of scheduling factors. Scheduling factors exist independent of the type of operation (i.e., short-haul, long-haul, ultra-long haul). For example, pilots report early morning report times and extended duty days as contributing to increased fatigue levels [11, 69]. Powell and colleagues found that it is not uncommon for pilot shifts to begin before 7 a.m. [69]. Thus, pilots are required to awaken near their low point in body temperature when sleep pressure is high and alertness levels are low. Additionally, sleep duration is often shortened due to sleep difficulties associated with trying to initiate sleep earlier the night prior in an attempt to compensate for an earlier wake time, which can be in conflict with the circadian system. In a sample of pilots observed over a 15-day period, sleep log and actigraphy data revealed that sleep prior to a duty day was reduced by almost 2 hours [70]. Consequently, these pilots begin their flight with a sleep debt, and if sleep is shortened across consecutive days, the debt can be cumulative. The sleep debt can also be aggravated by extended duty days involving work hours that continue into biological night. Thus, aviation schedules that require combinations of early start times and late evening (or early morning) end times make it difficult to maintain a regular sleep/wake cycle and reduce the opportunities available for recovery sleep. Research has shown that long-haul pilots commonly are awake longer than 20 hours, particularly on upwind flight segments [77, 41]. Schedules that involve short turn-around times between flights, resulting in an increase in takeoffs and landings and additional time constraints contributing to an increased workload, challenge short-haul crews. Short-haul pilots have reported that schedules consisting of 4 to 5 legs of flight are one of their more fatiguing schedules to fly [11].

b. Common Scheduling Factors. There are several common scheduling factors that can have major impact on sleep and alertness.

(1) Time Awake Prior to Duty. It is not just the duration of the duty day that is important. Time since awakening before the crew starts their duty period is equally, if not more, important. With the manufacturing of ultra long-range (ULR) aircraft and duty times approaching 20 hours, extended waking hours become unavoidable. Thus, time since awakening continues to become a more significant factor contributing to fatigue levels of flightcrew. Data collected from glass cockpit rated pilots during a simulated ULR flight found that pilots who departed at night, after being awake for at least 13.5 hours, had significantly reduced reaction times compared to pilots who departed during the morning hours, after about 3.5 hours of wakefulness. Pilots in the nighttime group were particularly impaired during the first half of the flight due to both sleep and circadian factors that were promoting sleep. However, towards the end of the flight, as continuous hours of wakefulness increased, performance decrements were seen in both morning and nighttime departure groups [15].

(2) Layover Sleep Opportunities. Upon arrival at layover destinations, sleep opportunities often conflict with a pilot's biological clock. For example, it can be local day at the layover city but the pilot's biological clock is programming them for sleep because it is nighttime at their home base. Thus, a crewmember's ability to obtain restorative recovery sleep is reduced before continuing duty. Obtaining optimal recovery sleep can also be a challenge if the layover city is in the same time zone as a pilot's home base. While there may be an opportunity for a crewmember to obtain a nap during the afternoon secondary WOCL [17, 28] in preparation for a nighttime departure, there is no guarantee that the individuals will be able to obtain sleep. Some individuals may choose not to take advantage of the napping opportunity, and others may not be able to nap at odd hours of the day. Therefore, it is essential that scheduled layovers include multiple sleep opportunities, and thus sufficient recovery sleep, prior to the return flight. Total sleep time per 24-hour period is one of the most influential determining factor of performance, even when sleep time is an aggregate of major sleep period and a nap (i.e., a split-sleep schedule) [63].

c. Opportunities for Recovery Sleep.

(1) Small reductions in sleep during a single trip may not cause serious changes in alertness and performance; however, if these small reductions are not made up after the trip prior to another trip, then the potential for serious accumulated sleep debt can occur. Studies have shown that an accumulation of only 1 hour of sleep loss per day over a week can have measurable effects on reaction time that may take several days to dissipate after the person returns to a normal sleep schedule [3, 87].

(2) Recent studies have also shown that rapid recovery from accumulated sleep debt requires that the person take deliberate steps to sleep *more* than the usual nominal 8 hours per day. It may take the average person several days of 9 hours of sleep or more to recover from a serious sleep debt. Hence, train staff to use recovery periods to sleep more than their usual amount to prevent accumulated sleep debt across an extended work or duty schedule.

d. Night Operations. Operational demands and advances in technology have led to the scheduling of flight operations throughout the 24-hour day. Thus, flight schedules require pilots to fly and shift workers to work on the "backside" of the clock, performing during times when they would normally be asleep. A survey of 739 airline pilots rated schedules involving nighttime inbound and outbound flights with daytime layover periods as especially fatiguing [11]. Nighttime flights involve increased continuous hours of wakefulness before duty, especially if the pilot was not able to obtain an afternoon nap. Thus, a person may frequently awaken in the morning and remain awake the entire day before duty begins in the evening for a night flight.

e. Circadian Shifts and "Jet Lag."

(1) Jet lag, resulting from crossing multiple time zones is another challenge in aviation operations, even for experienced flightcrews [53]. The rate of adaptation after crossing multiple time zones depends on both the number of time zones crossed and the direction of travel. Adjustment to westward travel is quicker than adjustment to eastward travel. Eastbound travel requires the individual to reduce their day to less than 24 hours (i.e., the circadian period is shortened), whereas westbound travel lengthens the circadian period [12, 76]. Lengthening the day and staying awake longer than 24-hours is easier because of the inherent period of the circadian rhythm being slightly longer than 24 hours.

(2) Circadian adaptation is less likely to occur during long-haul trips of less than 3 days because it does not allow enough time for resynchronization of internal biological rhythms with the external environment; therefore, pilots can minimize circadian disruption by keeping the most similar sleep/wake schedule to their home time zone as possible [57]. However, the exact timing of the circadian clock and rate of adaptation with multiple time zone crossings is not easily predictable, and thus a prescriptive formula for calculating a precise number of days needed for circadian adaptation in long haul crews is difficult without considering physiological, environmental, and operational factors [41].

f. Shift Work Operations. Fatigue is not only a challenge for flightcrew but is inherent in aviation shift work operations including Air Traffic Control and ground maintenance operations. Due to around-the-clock aviation operations, air traffic and ground personnel are faced with shifted schedules that interfere with ‘normal’ sleep/wake cycles that permit night-time sleep and daytime work. Shift work has traditionally included only night work and rotating shift schedules, however, the modern definition is more comprehensive. It includes any schedule that can potentially affect both sleep and circadian rhythms. Specifically, any schedule outside the traditional 7 a.m.-6 p.m. timeframe can be categorized as shift work and such shifts are becoming increasingly common [84].

(1) Sleep difficulties are commonly associated with shift work because sleep disturbances and sleepiness are the most commonly reported complaints of shift workers [55, 66, 84]. Although false, it is a not uncommon belief that as the shift worker adapts to their schedule over time and gets used to the non-standard shift, all of their problems associated with shift work are alleviated. However, shift work is not just about sleep; it is a more complex issue.

(2) Shift work is not simply a term used to describe non-standard schedules. It also is associated with the disruption of an individual’s underlying physiology. Shift work requires people to override the internal biological clock that programs humans for daytime activity and nighttime sleep [9]. This produces circadian misalignment, a condition in which the biological clock remains synchronized to the local time, driven by exposure to the local pattern of sunlight, but the sleep/wake cycle is out of sync with the local time. In other words, the sleep period is occurring at an adverse circadian phase, when the body is programmed to be awake. As a result, one can experience sleep difficulties (e.g., longer than normal times to fall asleep and early termination of sleep) resulting in continuous partial sleep deprivation and chronic sleep loss. The shift worker is further challenged by the fact that his or her sleep/wake cycle is constantly altered between work days and non-work days due to conflicting time cues from the day/night cycle and a day-oriented society (e.g., keeping the same day schedule as the family on non-work days).

(3) A number of common scheduling factors disrupt sleep and circadian rhythms and affect alertness and performance of shift workers in aviation environment. These work schedule factors might include early start times, variable work periods, insufficient recovery time, consecutive work periods, and on-call status, among others.

10. PREDICTIVE MODELS OF SLEEP, FATIGUE, AND PERFORMANCE.

a. Biomathematical Models of Fatigue and Performance. Predictive modeling algorithms can forecast the effects of fatigue on performance and risk. These models can be an important tool for work scheduling. Modeling can help minimize fatigue related errors, incidents and accidents during flight operations or shift work environments. These models are scheduling tools that can help to quantify the impact of underlying interaction of sleep and circadian physiology on performance levels.

(1) The theoretical framework of most of these models is the two-process model of sleep and alertness [1] that incorporates mathematical simulations of the two major processes in Figure 1, sleep regulation and circadian variation. Several initiatives are currently underway that incorporate the application of biomathematical modeling software to:

(a) Predict the times that neurobehavioral functions and performance will remain constant,

(b) Establish ideal time periods for maximal recovery sleep, and

(c) Determine the cumulative effects of different work-rest schedules on performance [59].

(2) Such models can serve as useful tools when evaluating the placement and timing of critical flight phases to assist in the scheduling of in-flight rest periods and layover sleep opportunities. While most of the biomathematical modeling software show promise in the prediction of performance, it is important that models used for scheduling have demonstrated validity for prediction of operational risk when applied with real world data [30]. In other words, one can plan with the model but must confirm the effect.

(3) The Federal Railroad Administration has sponsored a study that validated the ability of a biomathematical model, considering only work schedule information, to predict the increased risk of accidents with reduced cognitive effectiveness and increased fatigue. Subsequent work demonstrated that the same model could predict an increased severity of accidents (property damage) with increased fatigue [50].

b. Limits of Modeling. Currently, predictive fatigue models describe the effects of sleep history and circadian rhythms on the performance of an average person, assuming that the person requires about 8 hours of sleep per night to remain fully rested and has a regular circadian rhythm that favors neither the morning nor the evening for peak cognitive alertness. Efforts are underway to design procedures to tailor fatigue models to the characteristics of individuals but those tools require performance information from the individual to direct the changes to the model. The availability of data and assumptions about initial conditions also limits modeling application. Any model must start at some point in time and must assume some initial level of fatigue prior to the period of examination. Most models assume a fully rested person at the start.

c. Sleep Estimation. While measurement of sleep is possible for research studies, it is seldom available for operational assessment or forecasting of fatigue. All two-process physiological models for fatigue require an algorithm to estimate the amount of sleep obtainable under a particular work schedule, since it is sleep that restores performance and wakefulness that exhausts performance. Sleep estimation requires a thorough understanding of how workers adapt sleep patterns to the demands of their work schedule. Sleep estimation assumptions that work well for one group of workers may not work well to predict sleep in another group of workers; hence, sleep estimation algorithms that drive fatigue models must be validated for the specific work group for reasonable concordance with their typical sleep patterns. This is particularly important for work groups adapted to night work, split shifts, or on-duty sleep schedules.

11. STRATEGIES TO MITIGATE THE EFFECTS OF FATIGUE.

a. Recovery Sleep. We know that the longer one works without adequate opportunity to sleep, the greater the need for recovery sleep to prevent an accumulation of fatigue across duty periods. To some extent, FAA regulations codify this principle and specify off-duty rest periods that are proportional to the prior flight time. We now recognize that what is most important from a fatigue perspective is the total duration of duty that limits sleep opportunities. In general, the longer the period of duty, the more likely that duty will interfere with the nominal requirement to obtain 8 hours of sleep per day. However, circadian factors are very important in this calculation; 10 hours of duty starting at 8 a.m. will interfere less with normal nighttime sleep than 10 hours of duty starting at 10 p.m. Hence, the calculation of needed recovery sleep is complex since it depends on the circadian timing of the duty periods. Furthermore, the effects of sleep restriction are cumulative and the longer the period of sleep restriction, the greater the need for recovery sleep. There is some evidence that prolonged sleep restriction can lead to a slowing of the recovery process.

(1) The duration of the recovery sleep will depend on the amount of sleep loss that occurs as a result of a sequence of duty periods. The amount of recovery sleep required to fully restore performance will increase with the total amount of missed sleep since the person was fully rested, that is, had sufficient sleep to be fully alert.

(2) The amount of recovery sleep required to repay the deficit from sleep restriction is related to the total amount of sleep debt. Since the sleep regulatory process is adaptive, the amount of sleep required to make up a deficit is less than the total number of hours of sleep missed; it does not take 8 *additional* hours of sleep to make up for an 8-hour accumulated sleep debt. However, since it takes 8 hours of sleep to balance a normal day of wakefulness, it will require more than 8 hours of sleep per recovery day to repay the debt. In general, if a person has experienced several days of sleep restriction below the nominal requirement of 8 hours per day, full recovery of performance may require several days of 9 hours or more sleep per day.

(3) For recovery sleep to be an effective mitigation, the schedule must permit an adequate number of recovery nights of sleep *and* the employee must be trained to use those recovery days efficiently by taking more than the nominal 8 hours of sleep per day. Hence, effective recovery sleep is a shared responsibility of the scheduler and the employee.

b. Napping. Sleep is the only way to reverse sleepiness. Therefore, at times when some amount of sleep is possible but limited, napping is the most effective physiological strategy for restoring alertness levels. Naps have shown to be beneficial for restoring both performance and alertness levels, especially during long periods of wakefulness [4, 5, 35, 60, 71, 72, 89, 91]. Even short naps of 25-30 minutes can have beneficial effects. Controlled studies have shown that a nap can yield significant improvements in subsequent pilot alertness and vigilance performance compared to similar pilots who did not receive the nap so methods that augment crews to permit napping outside the cockpit is a viable fatigue countermeasure under current FAA rules. The FAA authorizes in-flight naps for flightcrew if there is an augmented complement so that two pilots are on the flight deck while the augmented crewmembers are resting. Although a number of foreign air carriers authorized in-seat cockpit naps during flight, the FAA does not authorize such in-seat cockpit naps [42].

c. In-Flight Rostering and Bunk Sleep (Flight-Ops Specific). In-flight rostering, although not commonly discussed as a fatigue countermeasure, can help minimize fatigue. It refers to the scheduling of augmented flightcrew to assigned positions on the flight deck, freeing other flightcrew to obtain in-flight rest or bunk sleep. In-flight rostering is directly related to the crew complement, or number of crewmembers assigned to the flight and is determined—in advance—during the scheduling process. Performance and alertness begin to deteriorate after 18-20 hours of continuous wakefulness [7]. However, an increased likelihood of incidents and accidents has occurred in shift workers after only 8-9 hour duty periods [39, 81]. In a review of aviation accidents, the National Transportation Safety Board (NTSB) found that when "time since awakening" exceeded the median for crew position, there was an increase in overall errors [67]. In light of these facts, it is essential to provide a sufficient number of crewmembers so that there are multiple opportunities for rest.

(1) The effects of continuous hours of wakefulness on alertness and performance can be minimized with the use of efficient in-flight rostering, which helps to ensure that at least one flightcrew member is always rested [16]. Use the following two principles:

(a) Scheduling bunk sleep periods that minimize the number of hours of extended wakefulness for the landing crew.

(b) Scheduling flightcrew to perform who just had a recent bunk sleep opportunity and have an increased chance of being well-rested during critical phases of flight.

NOTE: It is essential to consider rostering in the planning stages of the flight, educate the crew about the rostering approach, and that the crew adheres to the rostering and napping schedule during the flight.

(2) There is a lack of research concerning the specific number of crewmembers necessary to guarantee adequate sleep opportunities for sufficient performance and safety in the context of extended aviation operations. Although it is clear that more crewmembers are necessary to improve the alertness of other crewmembers, an empirical and evidence-based approach is needed to improve the current situation [16].

(a) The ULR Crew Alertness workshops of the FAA's 2008 Fatigue Symposium showed that ensuring adequate bunk sleep is one of the most important in-flight countermeasures to use to address sleep loss and circadian disruption during extended aviation operations [37]. The only way to reverse cumulative sleep debt is to obtain sleep because it addresses the underlying physiology of sleep loss. For example, if flight demands permit, physiological sleepiness can be reduced by utilizing periods of increased sleepiness during circadian low points, which, in turn, can contribute to increased quantity and quality of bunk sleep [17, 24, 26]. Thus, in-flight sleep periods are an operationally feasible approach to manage sleep loss associated with complex aviation schedules (e.g., extended wakefulness, crossing multiple time zones, and nighttime duty hours).

(b) Although proper bunk-sleep scheduling is both a feasible and operational approach for managing alertness, scheduled sleep periods often occur at less than optimal time periods due to conflicting crewmember job responsibilities. Therefore, efforts should be made to optimize the in-flight sleep periods for the primary crew, who have responsibility for critical flight maneuvers such as landings and takeoffs. Timing of in-flight sleep for the primary crew must be part of the rest planning process.

(3) Crewmembers have indicated that environmental factors in the bunk facilities influence the quality of in-flight rest periods. A NASA survey revealed that the most common factors that conflicted with quality bunk sleep were ambient temperature, noise from the galley and elsewhere, and background lighting [75]. Pilots who completed the survey also indicated that making the bunk facilities more private and having comfortable bedding and blankets would help promote better quality and quantity of bunk sleep. Many of these issues can be addressed during the design stage of bunk facilities.

(4) Finally, the duration of in-flight rest breaks (sleep opportunities) should be limited to no longer than about 6 hours. Studies have shown that even when given longer than 6 hours to sleep in the bunk, relatively few crewmembers can take advantage of that additional time. Merely providing pilots with more sleep opportunities does not guarantee that they will obtain more sleep. For example, flightcrews given a 5-hour bunk sleep opportunity obtained only around 3 hours of sleep, on average [46]. Signal and colleagues found that flightcrews who had a 7-hour sleep opportunity obtained, on average, only 3 hours 25 minutes of bunk sleep [79]. This is due to a range of factors that limit the length of time a pilot can remain asleep in the bunk and the need to limit the continuous in-seat time of the relief crew. Given the time to prepare for sleep and then return to duty after sleep, in-flight measurements indicate that actual bunk sleep times seldom last longer than 5 hours. In light of the limitations on rest break utilization, two rest breaks of 3 to 5 hours each are probably better than a single break of 8 hours for long duration flights. Plans for utilization of in-flight bunk sleep opportunities must consider multiple interacting factors.

(a) Length of in-flight sleep needed to remain alert at critical phases of flight;

(b) Circadian timing of the sleep opportunity;

(c) Need for occasional use of the toilet facility outside the rest facility;

(d) Length of in-seat time of the relief crew;

(e) Comfort, vibration, turbulence, and noise that can fragment sleep;

(f) Time needed to undress and redress for duty; and

(g) Time after sleep to wake up and become fully alert—dissipate sleep inertia.

d. Activity Breaks. Short breaks can serve to increase alertness by reducing the monotony of a highly automated cockpit environment through conscious disengagement with the flying task and, possibly, by allowing mild physical activity, depending on the type of break and the behaviors allowed during the break. Although not as effective as some other countermeasures, anecdotal reports from pilots indicate that many take brief, out-of-the-seat breaks as a fatigue countermeasure.

(1) Several studies indicate an improvement in alertness and performance associated with a cognitive break from continuous tasks. Even short 5-minute breaks can relieve monotony, increase overall productivity, and reduce reports of physical fatigue [40]. Others studies have shown that breaks also can have positive effects when individuals are experiencing partial or total sleep loss. Two total sleep deprivation studies ranging from 54 to 64 hours of continuous wakefulness revealed that participants who received 5 20-minute rest breaks exhibited improvements in performance, alertness, fatigue, and overall mood compared to participants who did not receive any breaks [45]. These physiological and performance improvements also have been observed in aviation environments, in which rest breaks have helped military pilots working sustained operations to overcome fatigue [2].

NOTE: Rest breaks are not a substitute for adequate sleep and not all studies have shown beneficial effects [83].

(2) Activity breaks that allow an individual to change posture by getting up out of their seat and walking or otherwise physically moving while engaging in increased social interaction can increase alertness levels; however, studies indicate that the beneficial effects can be short-lived, especially when the crew have been awake for more than 18 hours [68, 61].

(3) The beneficial effects of breaks are due in part to postural changes that occur when a pilot temporarily hands off flight-related tasks. There are consistent results from laboratory-based sleep deprivation research examining the effects of posture. Simply standing up can increase physiological arousal, decrease reaction times, and increase measures of attention in drowsy subjects [25].

e. Light. Research has shown that the use of properly timed bright light can shift human circadian rhythms. In addition, some research suggests that light may have an immediate and acute alerting effect on mood and performance, independent of its circadian phase-shifting capacity. The alerting effects of light may be a result of its suppression of melatonin, a neurotransmitter released in the mid- to late-evening. Therefore, light may be a powerful mitigator of the usual alertness and performance decline common to nighttime duty, especially during aviation operations.

(1) Bright light is not necessary for measurable improvements in alertness. Cajochen and colleagues showed measurable increases in subjective alertness and reductions in slow eye movements with normal indoor lighting (100-200 lux) [14]. Short wavelength light in the blue portion of the spectrum appears to have the greatest alerting effect [56] with the spectrum of typical room light containing enough energy in the shorter wavelengths to be effective.

(2) The alerting effects of light may be independent of time of day, making light a possible daytime countermeasure for those who have experienced prior sleep deprivation, and thus improve alertness and performance.

(3) Finally, while light can have beneficial effects while at work, exposure to sunlight after a night shift could inhibit the ability to get to sleep in the morning [78]. This is primarily due to the alerting effects of light and suppression of melatonin. Therefore, avoid sunlight after a night shift and prior to a morning sleep period, when possible.

f. Caffeine. Caffeine can be an effective countermeasure in improving alertness and performance levels [8, 88, 93]. Caffeine takes 15-30 minutes to enter the bloodstream after consumption, and thus alertness effects do not occur immediately. However, its effects can persist up to 5 hours after ingestion. Another characteristic of caffeine that makes it a common countermeasure used by pilots to maintain alertness is that it is readily available in beverages such as coffee, tea, and soft drinks. Minimal use of caffeine is not generally associated with the undesirable effects often associated with chronic use (i.e., tolerance, gastrointestinal problems, increased blood pressure, etc.). Individual differences exist in people’s response to caffeine including its effect on performance levels and sleep structure. Before using caffeine as a fatigue countermeasure, individuals should ground test it (as with any countermeasure) to determine its specific effects with their physiology.

12. IDENTIFYING FATIGUE IN AVIATION OPERATIONS.

a. Studies of Fatigue in Simulators and Operational Environments. Both simulator and in-flight studies conducted during flight operations and within shift work environments have documented that fatigue impairs central nervous system functioning.

(1) Long-haul pilots are particularly susceptible to vigilance lapses during low-workload periods, and such lapses could simultaneously appear in both crewmembers at the same time [13].

(2) In-flight recordings of brain activity have found that pilot micro-sleeps occurred most frequently during the cruise portion of long haul operations (in the middle-to-late segments of the flight) and that micro-sleeps were more than 9 times as likely during nighttime flights compared to daytime flights [94]. Spontaneous micro-sleeps increase with increasing flight duration [77].

(3) Despite strong motivation to be alert during the final stages of a flight, studies of brain activity and eye-closures indicate that physiological micro-events can occur during the period from top-of-descent to landing [74].

(4) Of the 1,424 flightcrew members responding to a NASA survey of fatigue factors in regional airline operations, 80 percent acknowledged having "nodded off" during a flight at some time [20].

(5) Results of a survey involving corporate/executive aviation operations, 71 percent of 1,488 flightcrew members reported having nodded off during duty [73].

b. Evidence of Fatigue from Accident Investigations. Fatigue has been, and continues to be, a contributing factor in aviation accidents. Currently, the NTSB has seven aviation fatigue-specific recommendations. Since 1993, the NTSB has determined that fatigue contributed to 7 air carrier accidents within the United States, resulting in 250 fatalities and 52 serious injuries. Recent events continually highlight the operational relevance of fatigue among flightcrew; it is not uncommon that crew fall asleep while flying. NTSB investigations have found that flightcrew on long duty days (a shift of more than 13 hours) exhibit a disproportionate amount of accidents when compared to those on short duty days (a shift of less than 13 hours). The longer the crews are awake, the more errors they tend to commit, especially cognitive errors such as decisionmaking.

(1) NTSB investigators divide the causes of fatigue into operational and personal factors. Operational factors contributing to fatigue induced by the workplace include short rest periods between shifts, which can be as short as 8 hours under current regulations, rapid rotation of shift start times, which can disrupt circadian rhythms, working early morning and graveyard shifts, and duration of commute, among others. Equally important are personal drivers of fatigue, which are largely habits and behaviors controlled by the individual, such as ensuring proper duration of rest. However, personal drivers of fatigue also depend on many factors such as the presence of sleep disorders, circadian variability, additional employment, and use of alcohol and stimulants.

(2) The table, below, of recent aviation accidents attributed in part to crew fatigue was presented during the NTSB keynote address at the FAA Fatigue Symposium.

Airline	**Date**	**Probable Cause**	**Outcome**
American International 808	1993	Impaired judgment, decisionmaking and flying abilities due to fatigue.	3 serious injuries.
Korean Air 801	1997	Crew failure to prepare for/execute non-precision approach.	228 fatalities; 26 serious injuries.
American Airlines 1420	1999	Flightcrew failure to discontinue approach and ensure that spoilers had extended after touchdown. Contributing factor was the flightcrew's impaired performance due to fatigue.	11 fatalities; 45 serious injuries.
Federal Express 1478	2002	Crew failure to establish and maintain proper glidepath at night. Fatigue was contributing factor.	3 serious injuries.

Corporate Airline	2004	Combination of fatigue related factors producing pilot error.	13 fatalities; 2 serious injuries.
Shuttle America	2007	Fatigue contributing factor affecting ability to plan and monitor approach leading to runway overrun.	No fatalities.

13. MEASUREMENT AND MITIGATION OF FATIGUE RISK.

a. Factors in Fatigue Risk. Fatigue due to extended work hours, time of day, and shift work induces reductions in vigilance and reaction time and increases in risk of poor decisions, human error, incidents, and accidents. As described earlier, cognitive fatigue results from the interaction of sleep limitations and circadian drives for sleepiness with time-on-task and cumulative duty time effects. Human error due to fatigue is the result of sporadic losses of brain function and attention that increase in frequency with reductions in sleep and circadian drive for sleep. Lapses in attention are random in time, making it difficult to demonstrate the role of fatigue in specific accident cases. Self-reported, subjective sleepiness cannot be relied upon in this context, because it has a low correlation with actual performance impairment. One way to understand the role of fatigue in accident risk is to consider that fatigue causes random periods of inattention that occasionally coincide with operational conditions that demand attention to avert a serious event or incident. Hence, accident risk increases when either:

(1) Lapses of attention increase in frequency due to sleep loss or circadian factors; or

(2) Work demands increase the need for attention.

b. Mitigation of Fatigue Risk. There are two main strategies to reduce fatigue-related accident risk: a) decrease fatigue factors that drive lapses in attention, or b) alter the job so that the task is less sensitive to lapses in attention.

(1) Factors leading to fatigue reviewed above—in brief, they are:

- Time since awakening,
- Cumulative sleep debt, and
- Circadian rhythm of attention.

(a) Determining how multiple fatigue factors combine to lead to heightened risk is difficult without the aid of a computer simulation of fatigue factors and how they combine to increase lapses in attention and heighten fatigue risk.

(b) Biomathematical fatigue models or simulations can derive from the work schedule and likely sleep under those schedules, and the fatigue factors that reduce performance and attention and increase risk of errors and accidents. Fatigue models can help improve performance and safety in operational settings by pointing to job-related factors, such as work scheduling, sleep opportunities, and individual sleep habits, which could be changed to reduce the chances of fatigue-related attention lapses that could lead to errors and accidents.

(c) Arranging for less schedule-induced fatigue is important but is only half of the equation. The staff and crews must use sleep opportunities effectively to be rested and prepared for duty. Training of staff and crews should provide basic information on fatigue as contained in this AC, including the measures that individuals should take to be fully rested for duty. Staff and crews need to know that alert performance requires sufficient sleep prior to duty and recovery sleep following duty to prevent cumulative sleep debt.

(2) Operators can modify the work environment to minimize the consequences of fatigue. For example, training of crews to work together better as a team—commonly known as Crew Resource Management (CRM)—can reduce the chances of fatigue-related mistakes. CRM training includes a range of knowledge, skills, and attitudes that improve the quality of communications, situational awareness, problem solving, decisionmaking, and teamwork. Taken together, these teamwork skills and procedures can catch fatigue-related errors before they adversely affect operations. In addition, the flight control systems themselves can be modified to provide alerts and warnings to pilots to supplement attention to the instruments, reducing the chances that a lapse of attention will lead to a mishap.

14. FATIGUE RISK MANAGEMENT.

a. Fatigue Risk Management System (FRMS).

(1) Prescriptive flight and duty time limitations and rest requirements reduce, but do not eliminate, the conditions that lead to fatigue. FRMSs potentially offer non-prescriptive procedures to reduce fatigue further by addressing the complexity of aviation operations and fatigue challenges associated with aviation operations. FRMSs are inherently evidence-based and include a combination of processes and procedures that are employed for the measurement, mitigation, management, and monitoring of fatigue risk within a specific operational setting [80]. Fatigue risk management programs provide an interactive and collaborative approach to address performance and safety levels of operations on a case-by-case basis, and, therefore, are more adaptive to the specific conditions that create fatigue in a particular operational environment.

(2) An FRMS employs a multi-layered defense to proactively manage operational fatigue risk. The defenses against fatigue risk can include the following levels of intervention:

(a) Flight and duty time scheduling,

(b) Employee training and individual sleep practices and hygiene,

(c) Teamwork and crew resource management, and

(d) Procedural and flight system barriers to error.

b. FRMS Applicability. An FRMS can be used within the envelope of prescriptive flight and duty time limitations or as an alternative to such prescriptive rules if it provides at least an equivalent level of safety. An FRMS enhances the capability of prescriptive flight and duty time limitations to provide an equivalent or enhanced level of safety based upon the identification and management of fatigue risk relevant to the specific circumstances. Use of an FRMS can allow greater operational flexibility and efficiency while maintaining safety by relying on in-flight measurements of sleep and alertness, including subjective reports by crewmembers, to monitor how scheduling affects flight and cabin crew alertness during flight duty.

(1) Commercially available computer models can be used to predict average performance capability from sleep/wake history and normal circadian rhythms. Models embedded within the FRMS process can help operators understand the likely effects on performance of sleep obtained before and during trip patterns. Such models, though not required, encapsulate the latest scientific research on human circadian systems, sleep, and performance capability and can be useful for rapidly estimating the likely fatigue levels associated with proposed new routes or schedule changes. However, certain assumptions and limitations need to be taken into account. They represent one useful component of an FRMS, but are not a substitute for an FRMS.

(2) An effective FRMS is data-driven and routinely collects and analyzes information and reports related to crew alertness as well as operational flight performance data. An FRMS's comprehensive range of safeguards helps to control the risk associated with both transient and cumulative fatigue. An FRMS based upon scientific principles and knowledge combined with sound methods of data collection and analysis can help maintain an equivalent level of safety while allowing greater operational flexibility.

c. FRMS as Part of a Safety Management System (SMS). Ideally, an FRMS should be an integral part of an operator's established SMS and its capability should be commensurate with the risk oversight needs. Whether within an existing SMS or as a stand-alone system, an FRMS applies SMS principles to proactively and continuously manage fatigue risk through a process requiring shared responsibility among management and flight and cabin crewmembers. Since feedback and non-punitive reporting from employees are essential elements of an SMS, a "just culture" is integral to any FRMS program. When properly implemented, an FRMS is a continuous performance improvement process, using feedback on the success or limitations of prior scheduling and fatigue mitigations to suggest improvements for future scheduling and fatigue mitigations.

d. Benefits of FRMS. Aviation carriers, regulators, and groups worldwide are addressing the benefits of incorporating FRMS programs into current aviation operations. Recent examples include easyJet, Air New Zealand, United Airlines, Continental Airlines, the Australia Civil Aviation Safety Authority, the Flight Safety Foundation, and the International Civil Aviation Organization (ICAO). Preliminary data from easyJet's FRMS program have demonstrated its effectiveness in reducing fatigue [82]. Air New Zealand has been a leader in demonstrating the operational benefits of an FRMS as presented at the FAA Symposium, "Aviation Fatigue Management Symposium: Partnerships for Solutions" on June 17—19, 2008 in Vienna, Virginia. Based on the available research and demonstrated success of such programs, the FAA is exploring ways to implement effective FRMS-based programs in operations where fatigue has been identified as an inherent risk. An FRMS offers a way to conduct safer flights beyond existing regulatory limits and is a promising addition to prescriptive flight and duty time and rest period regulations.

ORIGINAL SIGNED by

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APPENDIX 1. REFERENCES

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